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AFTAC USAF ltr 25 Jan 1972

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Acknowledgment: This research was supported by the Advanced Research Projects Agency, Nuclear Monitoring Research Office, under Project VELA-UNIFORM, and accomplished under the technical direction of the Air Force Technical Applications Center under Contract No. F33657-70-C-0311.

STATISTICAL DISCRIMINATION

Quarterly Report No. 3

1 March 1970 to 31 May 1970

Stanley J. Laster, Program Manager
Area Code 214, 238-6521

TEXAS INSTRUMENTS INCORPORATED
Services Group
P.O. Box 5621
Dallas, Texas 75222

Contract No. F 33657-70-C-0311
Amount of Contract: \$222,240
Beginning 25 August 1969
Ending 14 September 1970



Prepared for

AIR FORCE TECHNICAL APPLICATIONS CENTER
Washington, D. C. 20333

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY
Nuclear Test Detection Office
ARPA Order No. 624
AFTAC Project No. VELA/T/0702/B/ASD

1 July 1970

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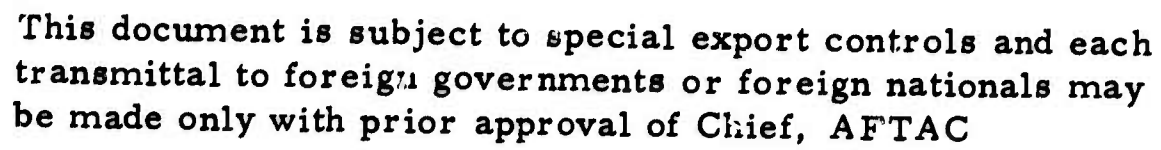
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TEXAS INSTRUMENTS

INCORPORATED

13500 NORTH CENTRAL EXPRESSWAY • DALLAS, TEXAS

SERVICES GROUP

1 July 1970

Headquarters
United States Air Force
AFTAC/VSC
Washington, D. C. 20333

Attention: Lt. John Woods

Subject: Third Quarterly Report Covering Period 1 March 1970
to 31 May 1970

Identification: AFTAC Project No.: VELA/T/0702/B/ASD
Project Title: Statistical Discrimination
ARPA Order No.: 624
ARPA Program Code: 9F10
Name of Contractor: Texas Instruments Incorporated
Contract Number: F33657-70-C-0311
Effective Date of Contract: 25 August 1969
Amount of Contract: \$222,250
Contract Expiration Date: 14 September 1970
Project Manager: Stanley J. Laster

Gentlemen:

MAJOR ACCOMPLISHMENTS (TASKS REFER TO WORK STATEMENT)

- (1) Short-period event classification studies are essentially complete except for the processing of thirty selected events at SAAC and eight events supplied by the contract monitor. The Seismic Event Classification Software Package has been modified to accept long-period statistics. Classification studies using both short- and long-period statistics are in progress.
- (2) The literature search comparing seismic signals from nuclear and chemical explosions is drawing to a close. Little useable information has been found concerning teleseismic characteristics of chemical explosions. At regional distances considerable information is available. Chemical explosions in water appear to be well recorded at teleseismic distance. A report is being prepared.

- (3) The Markov spectral estimate technique has been applied to a suite of theoretical seismograms. All the modes, both normal and leaking, show up well. However, there is a considerable scatter in the estimated dispersion. It is thought that the prediction filters used to generate the Markov spectral estimates are too long. Dispersion estimates using shorter filters are being run. Preliminary results for the theoretical data are discussed in the addenda to this report.
- (4) Long-period spectra and discriminants have been computed for 39 earthquakes and 25 explosions of various body wave magnitudes. Thresholds are being determined for usefulness of the various discriminants for identifying earthquakes and explosions. The discriminants used are discussed in the addenda to this report.

ACTION BY AFTAC

None

FINANCIAL STATUS

Financial status for this contract will be reported in the AMSR to be submitted the first week in July.

Very truly yours,

TEXAS INSTRUMENTS INCORPORATED



Stanley J. Laster
Program Manager

SJL:dmo
Attachment

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CLASSIFICATION

REPORT OF PROGRESS AGAINST SELECTED MILESTONES

(See instructions on reverse before filling in)

1. ARPA ORDER NUMBER

624

2. PROJECT

AFTAC Project No. VELA T/0702

3. COMPONENT

SEISMIC DISCRIMINATION TECHNIQUES

4. NAME AND LOCATION OF PREPARING ACTIVITY

Texas Instruments Incorporated

Services Group

Dallas, Texas 75222

5. CONTRACT NUMBER

F33657-70-C-0311

6. REPORT FOR MONTH ENDING

31 May 1970

Code a	Milestone b	Scheduled Completion Date c	Estimated Completion Date d	Date Completed e	Remarks f
A-1	Checkout SECSP programs; send to Washington; successfully process one event	1 Dec 69		15 Jan 70	
A-2	Determine discriminants to use in SECSP; submit recommendation to AFTAC for approval	15 Dec 69		1 July 70	
A-3	Specify offline processing needed to use LP discriminants in SECSP for data recorded at LASA	15 Nov 69		1 June 70	
A-4	Determine modifications necessary and statistics to use in applying SECSP to ALPA events	1 Jan 70	1 May 70		
A-5	Complete processing of Eurasian seismic events (recorded at LASA and ALPA) using SECSP	1 Sep 70	1 Sep 70		
A-6	Prepare special report summarizing results of SECSP processing	15 Sep 70	15 Sep 70		
B-1	Conduct literature search and publish report on differences between seismic signatures of nuclear and chemical explosions	1 May 70	15 July 70		
C-1	Obtain data ensembles with continental paths recorded at LASA and ALPA	15 Feb 70	1 July 70		
TYPED NAME AND TITLE Stan Laster, Program Manager		SIGNATURE		TELEPHONE 214- 238-2997	DATE SIGNED 1 July 70

SD FORM 350
1 JAN 69

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CLASSIFICATION

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REPORT OF PROGRESS AGAINST SELECTED MILESTONES

(See instructions on reverse before filling in)

1. ARPA ORDER NUMBER
6242. PROJECT
AFTAC Project No. VELA T/07023. COMPONENT
SEISMIC DISCRIMINATION TECHNIQUES4. NAME AND LOCATION OF PREPARING ACTIVITY
Texas Instruments Incorporated5. CONTRACT NUMBER
F33657-70-C-0311

Services Group

6. REPORT FOR MONTH ENDING

Dallas, Texas 75222

31 May 1970

Code a	Milestone b	Scheduled Completion Date c	Estimated Completion Date d	Date Completed e	Remarks f
C-2	Prepare special report comparing various methods of detecting and isolating higher-mode surface waves and usefulness of such waves for discrimination	15 May 70	1 Aug 70		
C-3	Investigate effectiveness of various methods for designing matched filters used in detecting long-period Rayleigh-wave energy	15 Jan 70	15 Mar 70		
C-4	Specify methods to use, if any, to remove noise before computing long-period discriminants	15 Dec 69	15 July 70		
C-5	Prepare special report discussing effects of noise on various discrimination statistics	1 Aug 70	1 Aug 70		
C-6	Specify statistics to use in evaluating combined discrimination capability of LASA and ALPA	1 Jun 70	1 Jul 70		
C-7	Complete processing of previously recorded LASA and ALPA events	1 Sep 70	1 Sep 70		
C-8	Prepare special report summarizing combined LASA-ALPA discrimination capabilities	15 Sep 70	15 Sep 70		
C-9	Prepare final report summarizing all research performed under contract	15 Sep 70	15 Sep 70		

TYPED NAME AND TITLE

Stan Laster, Program Manager

SIGNATURE

TELEPHONE

214-
238-2997

DATE SIGNED

1 July 70



ADDENDA



SECTION I

LONG-PERIOD DISCRIMINATION STUDIES

A. DISCRIMINANTS

A program (LPSTAT) was written to calculate the following statistics from long-period recordings. (Throughout the following "signal" refers to any energy in the signal time gate. Similarly for "noise".)

- AR parameter for signal gate (normalized to a distance of 80°)
- AR parameter for noise gate (normalized to a distance of 80°)
- AR of signal minus noise
- Delay time to the signal maximum
- Surface wave magnitude estimate computed from the signal maximum
- Period of the signal maximum
- S/N Ratio (zero-to-peak signal maximum/RMS noise)
- S/N Ratio (RMS signal/RMS noise)
- RMS parameter for signal gate (normalized to a distance of 80°)
- RMS parameter for noise gate (normalized to a distance of 80°)
- RMS of signal minus noise
- Spectral Ratio for signal gate
- Frequency at which the spectral peak occurs
- Chirp Statistic (amplitude of the chirped waveform corrected for distance and magnification)

These discriminants may be calculated for all three components (vertical, inline, transverse). In addition, the AR and RMS parameters are averaged over the number of components input. The chirp filtering is iterative where in the time duration of the chirp filter is successively altered until the



maximum crosscorrelation of the filter with the time trace is obtained (see below).

Long-period discriminants have been calculated from the vertical component of the Rayleigh wave signal for an ensemble of 39 earthquakes and 25 explosions for which short-period P-wave discriminants are also available. Two dimensional plots of these discriminants are being prepared.

Next, learning patterns will be formed to test the effectiveness of various combinations of long- and short-period statistics in the classification process.

B. CHIRP FILTERING

Several techniques were investigated wherein the length of a chirp filter is iteratively adjusted to yield the maximum crosscorrelation between the filter and the time trace. The most stable technique involves calculating the maximum amplitude of the output for three different length filters. The chirp length associated with the maximum of the function is determined using three-point quadratic interpolation. A chirp filter of that length is then calculated and applied to the trace and the maximum amplitude of the output determined for use in the next three point interpolation. The process is repeated 3 times and the maximum amplitude obtained is used for calculating the chirp statistic. This technique has proved to be more effective than using a chirp length based on epicentral distance and assumed group velocities, but requires somewhat more computer time. A single chirp operation takes about .1 minutes (IBM 360/65) in the time domain, while the iterative procedure takes from .3 to .5 minutes (typical chirp and record length). Both operations are much faster when performed in the frequency domain.

SECTION II

DETECTION OF LONG-PERIOD HIGHER MODE ENERGY

The characteristics of the maximum entropy spectrum analysis technique were investigated further by applying it to seismograms of precisely



known content. The purpose of this was to perhaps explain some unexpected results for the two events examined and discussed in the last report. The seismograms, generated under a previous contract, were synthesized from the solution of the equations describing a single layer on an infinite half-space. Details of the original work are contained in the published report.¹

As the original seismograms were direct simulations of an existing analog model, scaling of the physical parameters of the layer model was done to make it a reasonable model, within the scaling constraints, of the earth. The scaling used was to let 1 cm (model) correspond to 20 km (real earth) and 1 microsecond to 4/3 second. This results in the model below

TABLE 1

P velocity (km/sec)	S velocity (km/sec)	Density Ratios	L
5.75	3.21	1.0	40 km
8.23	4.86		

This model is not as close to a typical continental crust as one might desire because (1) The crustal velocity is somewhat too low, (2) The crustal thickness is somewhat too small, and (3) The mantle density should be larger than the crustal density. Nonetheless, the model is adequate for the analysis used.

The vertical seismograms of four modes: M_{11} , M_{21} , PL_{21} , and PL_{22} were computed for distance from 1000 km to 9400 km at 400 km increments. The PL_{21} and PL_{22} modes are the first and second order leaking modes while the M_{11} and M_{21} modes are the Rayleigh and first higher shear modes.

¹ Laster, S., Foreman, J., Linville, A., Theoretical investigation of model for a layer over a half-space: Geophysics, vol. XXX, No. 4, August 1965.



These four modes are shown for a distance of 5000 km in Figure 1a, 1b, 1c, and 1d. Note that the vertical scale is different for each mode. The composite seismogram, the sum of the four individual modes are shown in 1e.

The composite trace was convolved by a filter intended to simulate the response of a long-period seismometer. The filtered composite trace is shown in Figure 1f and the frequency response of the seismometer is shown in Figure 2. The actual LASA L.P. seismometers have peak response around 0.04 Hz; however, to create a reasonable seismogram similar in appearance to real LASA seismograms the peak response was lowered to 0.03 Hz.

In addition to the pure event signal, the composite was mixed with random noise, itself having been filtered by the seismometer response. Signal-to-noise ratios of 10:1 and 50:1 were used (signal zero-to-peak/noise rms). These traces are shown in Figures 1g and 1h.

The seismograms shown in Figure 1 are being individually analyzed by the maximum entropy technique. Preliminary results indicate the following conclusions:

- The accuracy of maximum entropy technique is strongly dependent on the precision of the calculations. From looking at the computed results it appears that large signal-to-noise events can introduce spurious peaks in the spectrum unless adequate machine precision is used.
- The present long-period data is oversampled. The response of the LASA seismometers produce strong cutoff above 0.1 Hz resulting in little power between 0.1 Hz and 0.5 Hz. This also causes problems related to adequate precision and the introduction of spurious peaks, when using the maximum entropy technique.
- The data should be antialias filtered and decimated to reduce the incidence of false spectral peaks. In addition, whitening of the data may also be desirable. These techniques are now being applied to the theoretical data and also some real long-period seismograms.

KA

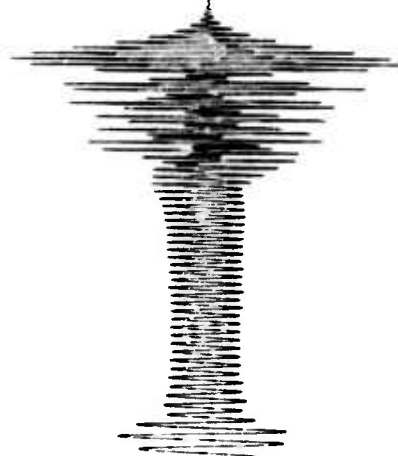
M_{11}

2.5×10^4



M_{21}

2.5×10^3



PL_{21}

5×10^2



5×10^2

PL_{21}

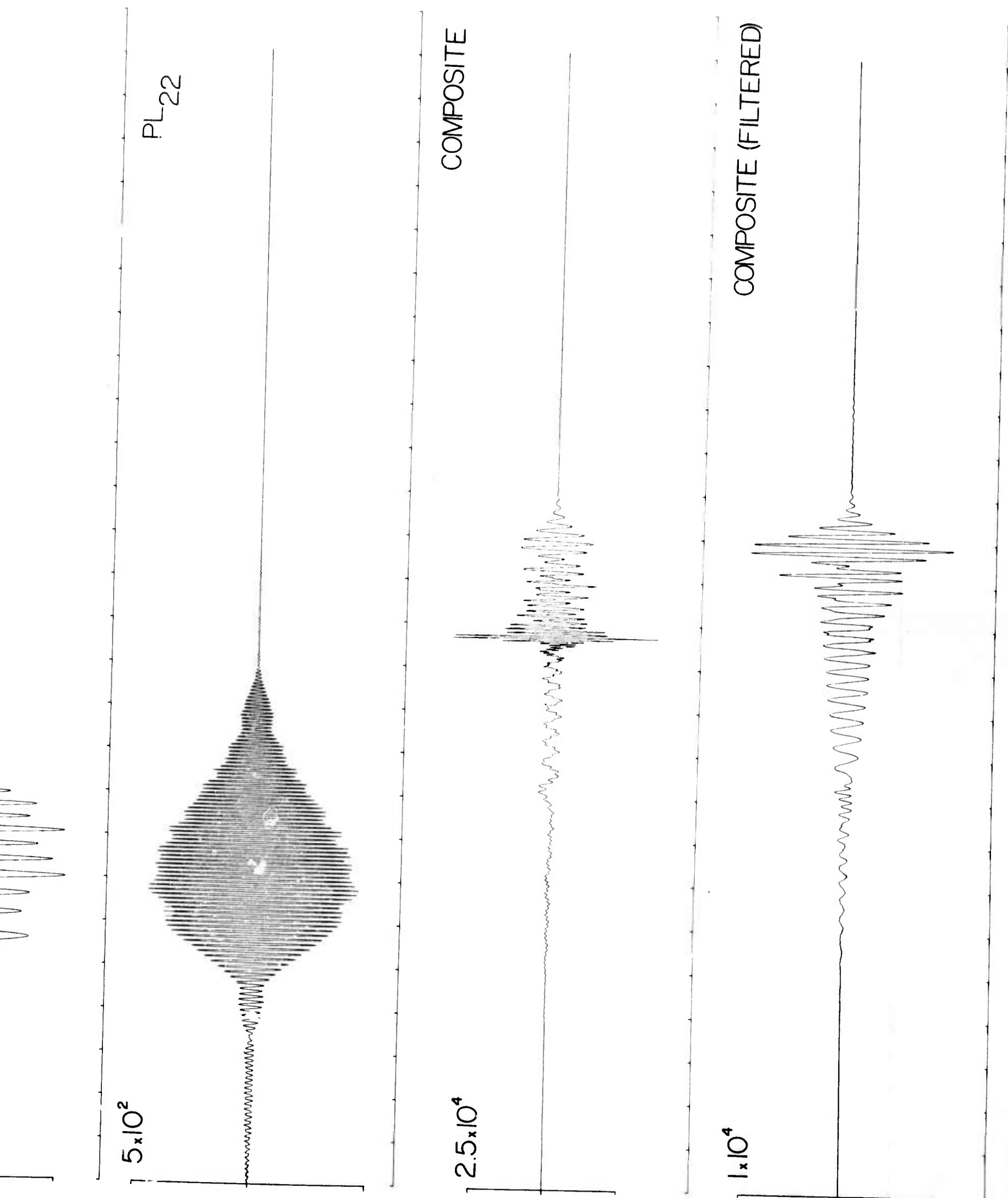


Figure 1. 1

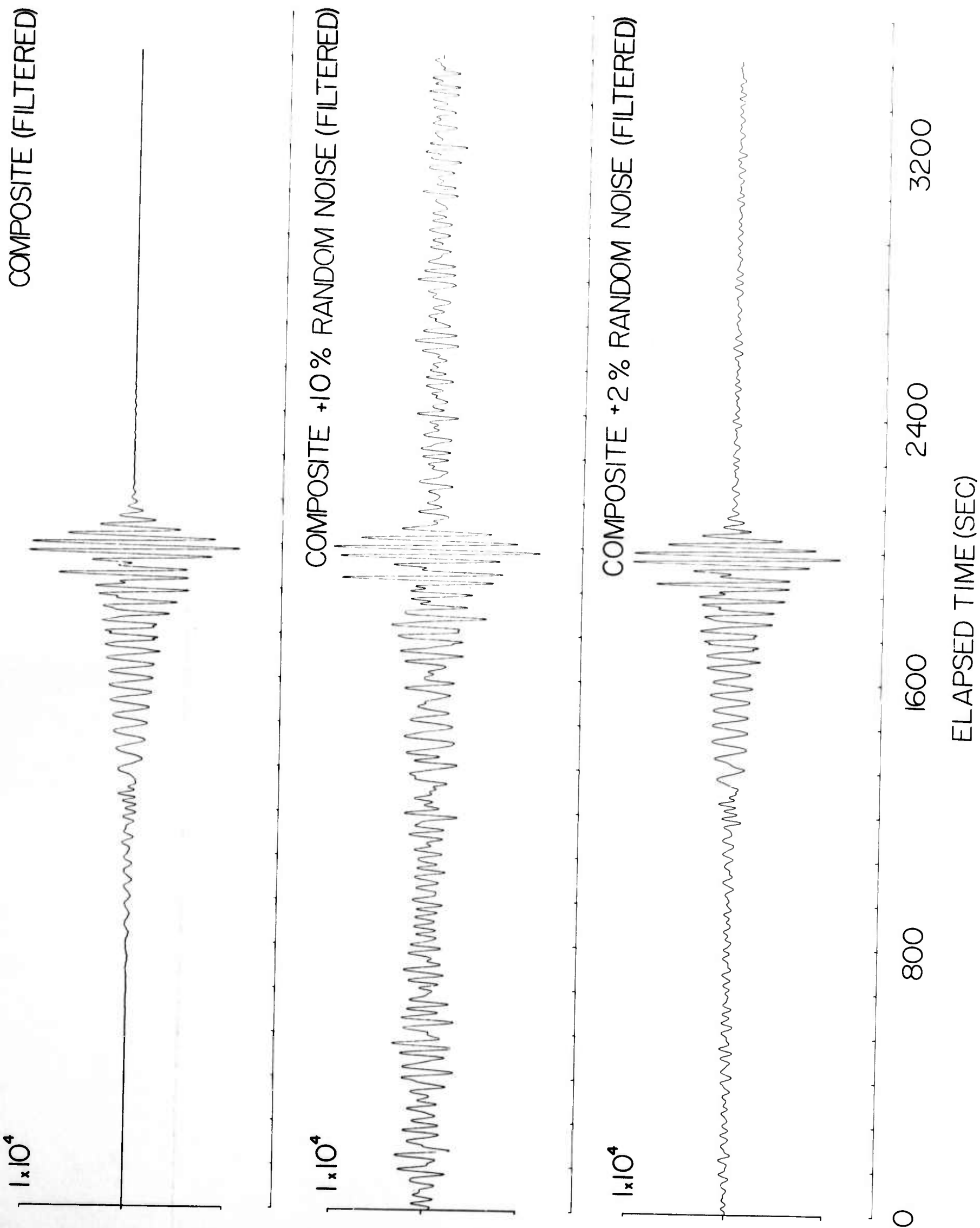
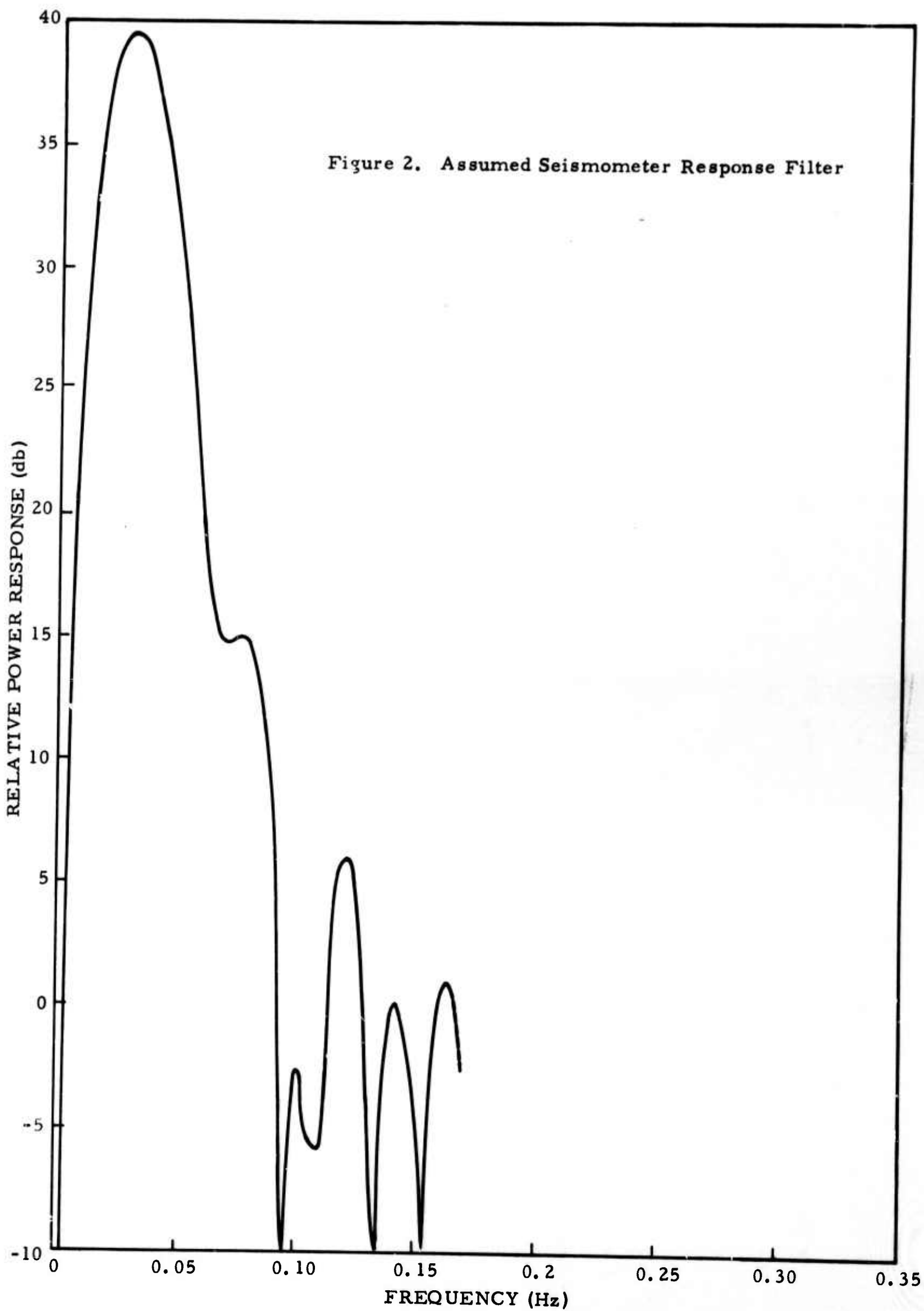


Figure 1. Theoretical Seismograms for Single Layer Crust Model



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Texas Instruments Incorporated

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Unclassified

2b. GROUP

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STATISTICAL DISCRIMINATION, QUARTERLY REPORT NO. 3

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Third Quarterly, 1 March 1970 to 31 May 1970

5. AUTHOR(S) (First name, middle initial, last name)

Stanley J. Laster, Program Manager

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10. DISTRIBUTION STATEMENT

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11. SUPPLEMENTARY NOTES

ARPA Order No. 624

12. SPONSORING MILITARY ACTIVITY

Advanced Research Projects Agency
Department of Defense
The Pentagon
Washington, D.C. 20301

13. ABSTRACT

Work done under this contract for the period 1 March to 31 May 1970 is reviewed. A description is given of the long-period statistics being studied. Chirp filtering of long-period events is done iteratively. A set of theoretical data, which has been constructed for use in the higher mode studies, is described.

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KEY WORDS

LINK A

LINK B

LINK C

ROLE

WT

ROLE

WT

ROLE

WT

Discriminant

Higher Mode

Chirp Filtering

UNCLASSIFIED

Security Classification